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2. Patent application number *(The Patent Office will fill in this part)* — 20 MAR 1998 — 9806046.0

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

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   Research Support & Industrial Liaison Office
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   Patents ADP number *(if you know it)*

   If the applicant is a corporate body, give the country/state of its incorporation — UNITED KINGDOM

4. Title of the invention — DENTAL CURING

5. Name of your agent *(if you have one)* — JEFFERY KEITH HOGG

   "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

   WITHERS & ROGERS
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Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*
UK	9720443.2	25.09.97.

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing *(day / month / year)*

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   a) any applicant named in part 3 is not an inventor, or
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Continuation sheets of this form	
Description	11
Claim(s)	
Abstract	
Drawing(s)	6

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Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	
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11. I/We request the grant of a patent on the basis of this application.

Signature Withers & Rogers Date

for Withers & Rogers (Agents) 20.03.98.

12. Name and daytime telephone number of person to contact in the United Kingdom JEFF HOGG 0117 9253030

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DENTAL CURING

This invention relates to an optical irradiation device, especially a compact portable irradiation device suitable for use as a light polymerisation source.

It has already been proposed to use light-emitting diodes LEDs in a hand held device to produce a focused beam of light to cure dental materials. Blue light at a peak wavelength of about 470nm is used to harden dental polymers which contain camphoroquinone as the photoinitator in a methacrylate polymerisation process. However, there is a problem in producing a sufficient level of irradiance even with a clustered array of LEDs, to cure the known dental polymers in the recommended time. At the lower levels of irradiance available generally below 300mW/sq.cm, longer curing times have to be allowed, which reduces the efficiency of the dental treatment delivered.

An object of the present invention is to provide an optical irradiation device that employs LEDs, and thereby has the benefits of compactness, portability, ruggedness and long life, but which also produces improved levels of irradiance at and above 300mW/sq.cm.

According to a first aspect of the invention, LEDs are clustered in an irradiation device by forming shaped faces on adjacent LEDs which allow them to abut more closely face-to-

face than they would otherwise with conventional spherical outer surfaces as manufactured currently.

According to a second aspect, the invention consists in an optical irradiation device employing LEDs and incorporating a heat pipe to cool the LEDs.

According to a third aspect, the invention consists in a heat pipe comprising inner and outer walls that extend longitudinally from one end of the heat pipe to the other and define an annular space therebetween containing a material that serves to absorb heat by a phase change, the annular space being divided by internal walls into a plurality of fluid flow channels that extend longitudinally between said ends, some of said channels being adapted to conduct the liquid/vapour phase of said material from the hot end of the heat pipe to the cold end, and other channels being adapted to return said liquid phase from the cold end of the pipe to the hot end.

According to a fourth aspect, the invention consists in an irradiation device employing LEDs and a tapered light guide to collect radiation emitted by the LEDs and deliver this to an output beam, wherein two or more tapered light guides are arranged in series so that successive guides receive radiation from preceding guides, and a group of LEDs is provided at the input end of each guide, each successive guide preferably being provided with a ring of LEDs around

the output end of the preceding guide.

The first aspect of the invention means that LEDs occupy more of the available space, and a fixed number produce a higher radiant intensity. Thus, smaller numbers of LEDs can be used to produce a desired level of irradiance, which in turn reduces the power required to drive the device and the heat generated by it. Furthermore, the device can be made more compact. Packing of the LEDs in this way may involve a slight reduction in the output of each LED, but the more effective packing density produces an overall increase in irradiance.

Typically, a central LED might have a polygonal outer surface, and a first ring of LEDs would be arranged around it, each with a flat face to abut a corresponding face of the central LED and possibly each having a pair of radiating side faces which abut adjacent LEDs in the first ring. Furthermore, a second or more rings of LEDs could be arranged concentrically with the first ring, each with respective adjacent flat side faces abutting one another and possibly with inwardly diverted faces abutting respective outwardly directed faces of the LEDs of the first ring. Additionally, a single ring of LEDs could be used without a central LED.

In one embodiment of the invention shown in Figure 1 hexagonal LEDs 11, may be clustered in the manner of a honeycomb. In a second embodiment of the invention shown in

Figure 2, a central hexagonal LED 21 may abut flat faces of six LEDs 22 in a first ring contained within a second ring of LEDs 23 with radiating side faces that allow adjacent LEDs in the second ring to abut one another. In a third embodiment of the invention shown in Figure 3, an inner ring of nine LEDs 31 in a first ring is contained within a second ring of LEDs 32 with radiating side faces that allow adjacent LEDs in the second ring to abut one another. In both the second and third embodiments, the adjacent faces of the LEDs of the first and second ring may also be shaped to abut one another. In yet another embodiment, the central group of LEDs 21,22 of Figure 2 may be replaced by ther same number of LEDs in a honeycomb cluster. Yet another embodiment may consist of the single ring of LEDs 31 shown in Figure 3. It will be appreciated in all three embodiments, the LEDs are mounted in a substantially flat plane.

In modifying the conventional characteristics of the optical sphere shape of a LED, the outer plastics envelope that encapsulates the light-emitting semiconductor Pn junction, will be modified, and thus care has to be taken to preserve as much as possible of the focusing effect of the envelope to maximise the total irradiance. Because the envelope of existing LEDs have a tapered shape to assist their removal from the mould during manufacture, the shaped side faces can be formed around the broader base of the LED to change its cross-section, for example to become hexagonal, but with these faces having a reducing effect on the shape of the

guide with the consequent more efficient transmission of radiant energy and increased illuminance. This improvement is most marked compared with a conventional approach of simply increasing the numbers of LEDs in a cluster at ever increasing diameters with decreasing beneficial effect on illuminance and increasing detrimental effect on compactness, heat generation and cost.

In one preferred embodiment of the invention, a single tapered light guide 41 is provided, as shown in Figures 4 and 5. If required, the light guide can be curved along its length. as shown in Figure 5, to direct the output beam to suit a particular application, this being a known practice with existing light guides. The light guide may be machined from cast acrylic plastic and bent, or could be made from glass or other optically transparent materials.

In another embodiment of the invention, two or more adiabatic tapered light guides 41 are arranged in series as shown in Figure 6. This arrangement allows the overall diameter of the device to be kept relatively small as the LED clusters 43 can be arranged in groups along the length of the device, successive groups forming a ring around the end of one light guide as it connects to the next.

Fused, fibre-bundle, light guides have the advantage of individual fibres being of a relatively small diameter so that they can be bent over a tighter radius without the

envelope towards its tip where the focusing effect of the envelope is concentrated. Thus the invention can employ existing LEDs and modify their shape in a secondary manufacturing process, for example, using jigs, or the invention can employ LEDs which have been specially manufactured with the required outer shape to accommodate better clustering.

The shaped facets of the LEDs may be polished to enhance reflection and help reduce any loss of optical powers. Additionally, a reflective metallic film may be applied to the shaped faces to further enhance reflection.

The LEDs may also incorporate a microlens or microlens array to aid collimation of the beam.

The device according to the invention also preferably incorporates tapered light guides to collect light emitted by the LEDs and deliver this as an output beam. It is known to use light guides with adiabatic optical tapers in optical irradiation devices so that there is total internal reflection of the light as it is conducted from the light source to the output. However, an advantage of the invention is that the more compact cross-section of the LED cluster means that the diameter at the input end of the light guide can be smaller, and thus a smaller angle of adiabatic taper (i.e. the ratio of the diameter of the input end to the output end of the light guide) can be provided in the light

axial and radial variation in refractive index. In this way, the numeric aperture can be varied at either end of the guide to achieve the desired transmission.

In alternative embodiments of the invention, instead of providing a single tapered light guide, each LED or groups of LEDs could be provided with its own light guide fibre incorporating an adiabatic optical taper, and the output ends of these fibres could be collected together to form a single output beam. The input end of the fibre would be moulded optically to the adjacent LED or group of LEDs for efficient transmission of radiation. In this way, the diodes can be spaced more widely to dissipate unwanted heat. In yet another embodiment of the invention, each LED could be adjusted so that its outer envelope is extended into a fibre light guide which incorporates an adiabatic optical taper. In yet another embodiment, the section of the fibres may be modified so that shaped faces of the fibres fit together to reduce the interstitial space. One embodiment of this design could be as shown in Figure 7.

It will be appreciated that the irradiance of the device according to the invention can be varied by varying the input power, number of LEDs, or by varying the adiabatic taper of the light guide.

Cooling of the LED cluster is aided by arranging that the electrical connections of each LED are thermally connected to

greater losses associated with larger diameter fibres when bent over the same radius. However, conventional fused-fibre bundles have the disadvantage of a packing fraction loss, that is, the outer cladding of the fibre uses up a significant proportion of the cross-section of the light guide into which light from the semiconductor array is directed, thus reducing the amount of transmitted radiation available from the semiconductor source. Preferably, therefore, in one embodiment of the invention, the guide comprises a few shaped fibres 61 placed adjacent to each other and fused as in Figure 7. A guide of this design is manufactured by MicroQuartz Sciences Inc. of Phoenix, Arizona, USA. In this way, the diameter of each fibre is smaller than a single homogeneous guide rod so that they allow greater light transmission on bending around the same bend radius, but also the packing fraction is also greatly reduced over conventional fibre guides, resulting in a greater than 90% core availability at the input end of the guide.

In another embodiment of the invention, a graded-index optical light guide is used. A graded-index light guide has no sudden interface between the cladding and the core. Instead, the refractive index varies either radially or axially. In one embodiment, the gradient of the refractive index of the light guide varies both radially and axially so that the light energy is favourably manipulated. A guide that uses a stepped index could also be used with the same

which are located in a hand grip 53 attached to the body 46, in Figure 5. However, the heat pipe design can be modified as shown in Figure 8 to accommodate batteries. The heat pipe consists of two concentric heat conducting tubes 55,56 with a folded interstitial heat conduction element 57 between these tubes similar in appearance to a length of corrugated sheet rolled into a tube. This lies within the concentric tubes. The wicks 58 of the heat pipe can then be placed in alternative grooves in the corrugated sheet, while the empty grooves 59 allow for the rapid movement of the vapour formed at the warmer end of the heat pipe.

By designing the heat pipe in this way batteries, capacitors, supercapacitors or other energy source 60 can be located within the inner wall 55 of the heat pipe.

In some embodiments, for example, where there are a large number of LEDs, a heat sink 51 may be necessary in addition to the heat pipe 45. The intermittent use of an LED irridation device for dental curing, means that with careful design, a heat sink may be omitted. If cooling to below the ambient temperature is required, such as may be the case in extreme environments, a Peltier device 50 may be added to the heat pipe, although a Peltier device will result in a greater consumption of power and a requirement for greater heat dissipation.

The wavelengths of the LED used will depend upon the

one or more heat pipes. Conventional LED irradiation devices usually include a heat sink to conduct away the heat from the LED chips. Heat sinks are a generally slow and inefficient in conducting heat away from a heat source compared with heat pipes. Heat pipes conduct heat away rapidly by using the latent heat of a substance, such as water, which is vaporised by the heat from the source. The vapour moves at high speed to the cooler end of the heat pipe and condenses. Heat pipes are unique in their ability to conduct heat rapidly in this way.

Figure 5 shows a device according to the invention which incorporates a heat pipe 45 as a single lumen in the main body 46 of the device. The hotter of the LED leads 44 is preferably placed nearer the heat pipe 45 or outer case 47 of the LED cluster so that the heat path of the hotter lead is shorter. A thermal connector 48 may be provided between the LEDs 43 and the end of the heat pipe 45. If required, additional forced cooling means may be used for example, a fan 49 or Peltier device 50 in juxtaposition to the pipe. In addition, a heat sink 51 may be provided.

Because of the greater cooling ability of heat pipes, they allow the LEDs to be driven in such a manner as to produce more radiation, and thus allows a more powerful device to be manufactured.

For portable use, the LEDs are operated from batteries 52,

applications of the device. A LED emitting blue light with a peak wavelength of about 470mm is used to harden dental polymers, but a LED emitting red light may be useful for photodynamic therapy, for example, cancer therapy.

The choice of LED is also important in terms of its construction, diameter, irradiance and light angular spread pattern, From a range of known LEDs the best available choice has been determined as that with a 3mm diameter rather than a 5mm diameter and an angular spread of 30 degrees rather than 15 or 45 degrees. Nichia is the manufacturer of these LEDs.

The power supply for the LEDs of the device according to the invention could be mains power, battery power, capacitor, supercapacitor, solar power, clockwork generator or generator powered by the mechanical effort of the operator or assistant.

In one embodiment, a capacitor or supercapacitor could be used to power the array having advantages over conventional rechargeable sources such as batteries. Capacitors can be virtually instantaneously recharged between one or more curing cycles of operation when the unit is connected to a power source.

FIG 1.

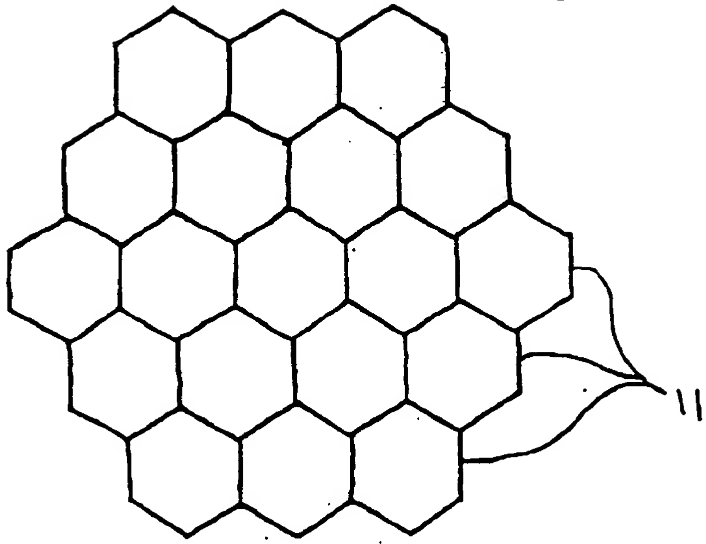

FIG 2.

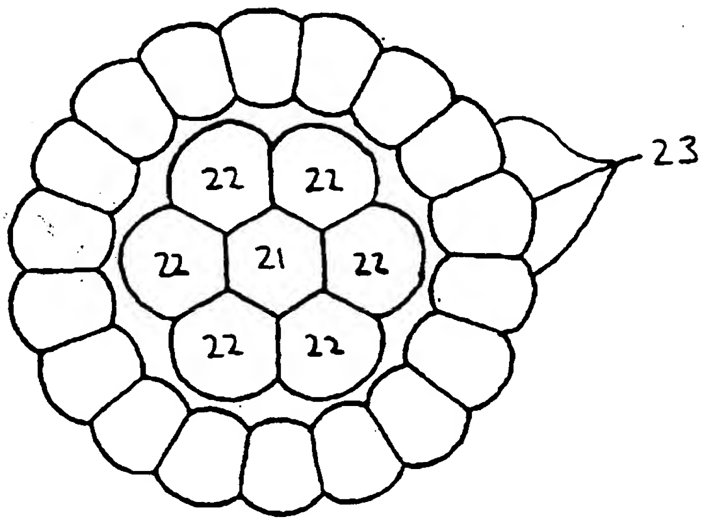

FIG 3.

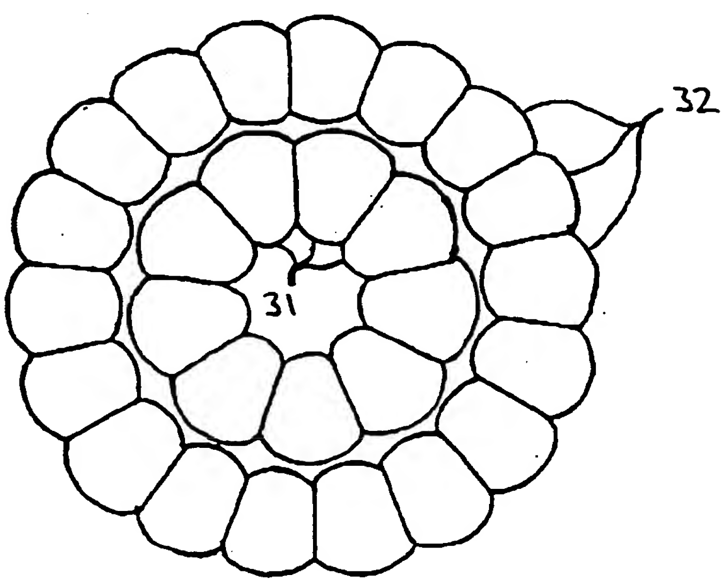

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FIG. 4

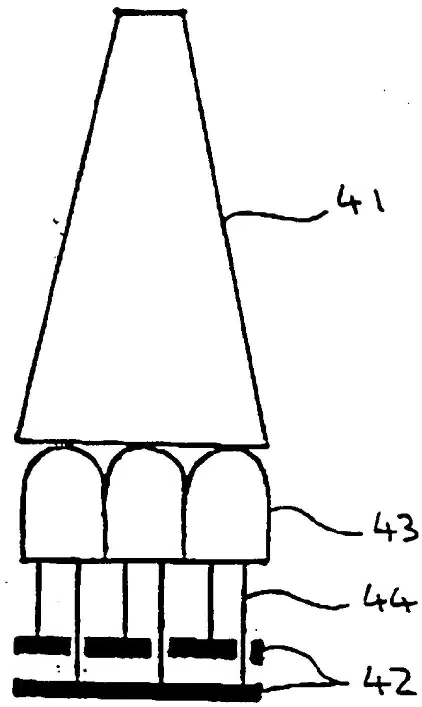

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FIG. 5.

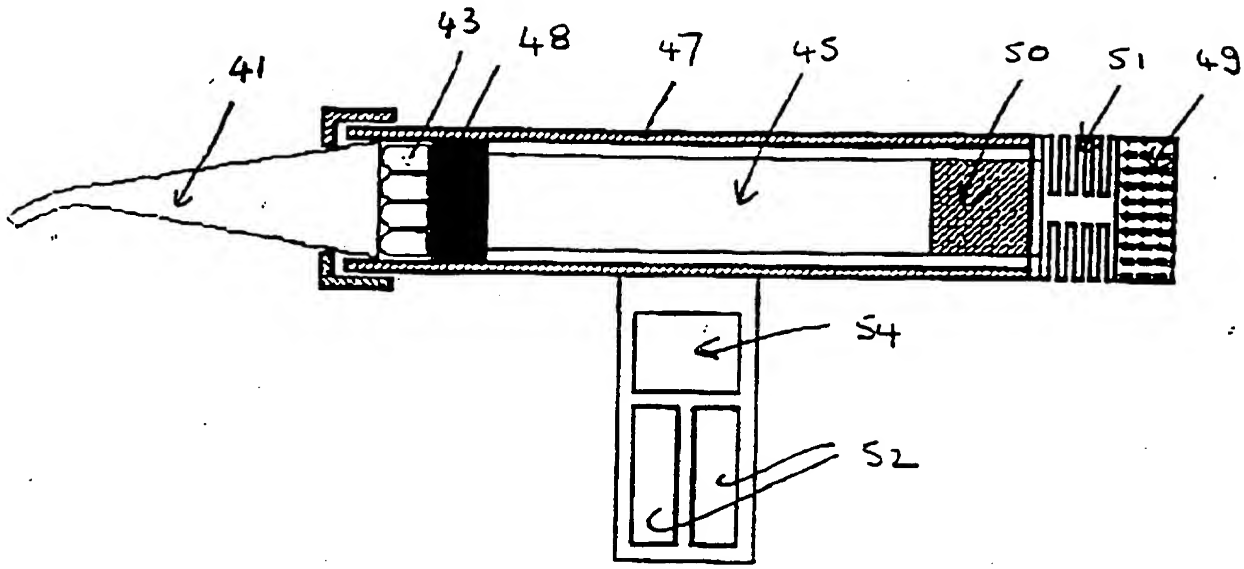

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FIG. 6.

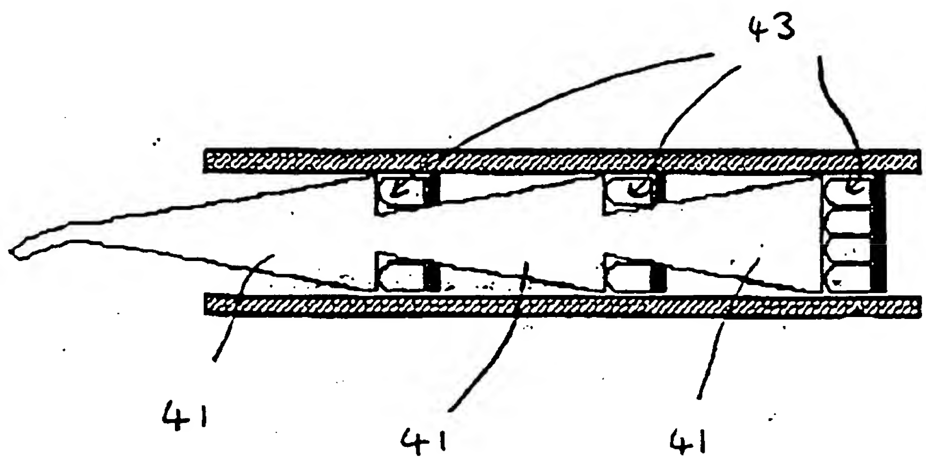

FIG. 7.

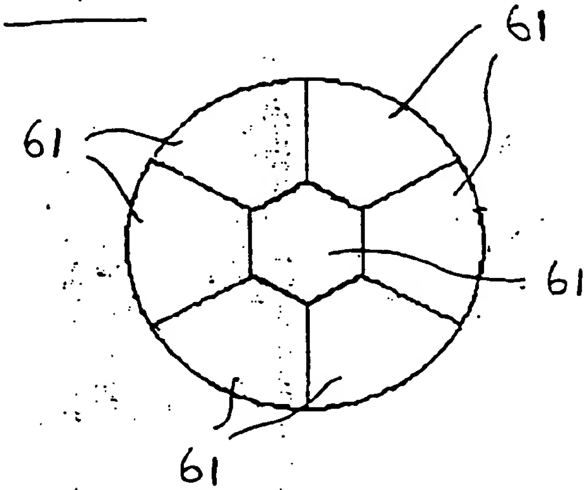

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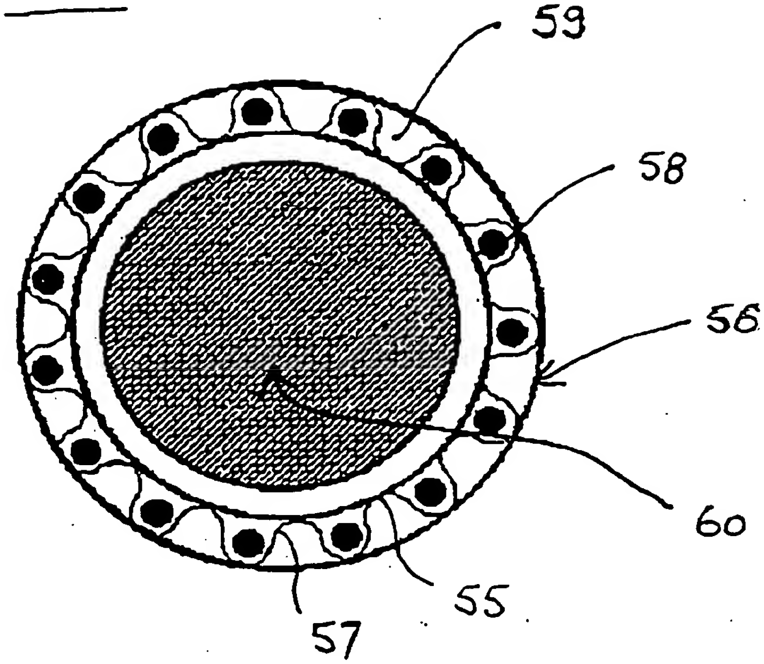
FIG. 8



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